Accounting for Ocean and Seabed Variability in Oceanic Waveguide Parameter Estimation

Kyle M. Becker
The Pennsylvania State University/Applied Research Laboratory
State College, PA 16804-0030
Phone:(814) 863-4159 Fax: (814) 863-8783 E-mail: kmbecker@psu.edu

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LONG-TERM GOALS

The long-term objective of this work is to develop methods for rapid assessment of seabed variability combined with detailed localized geoacoustic inversions to characterize the bottom for shallow-water environments. Consideration is given to spatial and temporal variability of water column properties common to shallow-water environments and their impact on inversion results. Advances made in the work will contribute to development of unified ocean/ seabed/ acoustic models and improved prediction capabilities for USW tactical decision aids.

OBJECTIVES

The objective of this research is to expand our understanding of propagation in shallow waters by incorporating high-resolution measurements of both the acoustic field and the ocean environment. The immediate goals of the proposed work are to address research issues relating to parameter estimation derived from acoustic field measurements in shallow water. Parameters of interest include seabed properties (sound speed, density, attenuation) and morphology along with source location. Issues to be addressed include: parameter estimation for geospatially varying bathymetry and sediments; the impact of water column variability on geoacoustic inversion; and the effects of Doppler shift in a waveguide on acoustic measurements and inversion. A particular goal is a comparison of inversion results based on modal eigenvalue estimates and modal dispersion obtained using different co-located data sets.

APPROACH

The approach is focused on analysis of both low-frequency acoustic and high-resolution oceanographic data collected during the Modal Inversion Methods Experiments (MIME) conducted August 2006. MIME was a component of the ONR Shallow Water 06 (SW06) experiment. Acoustic data were collected along synthetic apertures created by a towed source emitting low-frequency, continuous wave (cw) tones (50,75,125, and 175 Hz) and for a stationary source transmitting a broadband signal with 250 Hz bandwidth. The acoustic data were measured on a fixed combined vertical/horizontal line array[1]. The magnitude of the acoustic pressure fields for a 50 Hz cw signal measured at three depths

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14. ABSTRACT

The long-term objective of this work is to develop methods for rapid assessment of seabed variability combined with detailed localized geoacoustic inversions to characterize the bottom for shallow-water environments. Consideration is given to spatial and temporal variability of water column properties common to shallow-water environments and their impact on inversion results. Advances made in the work will contribute to development of unified ocean/ seabed/ acoustic models and improved prediction capabilities for USW tactical decision aids.

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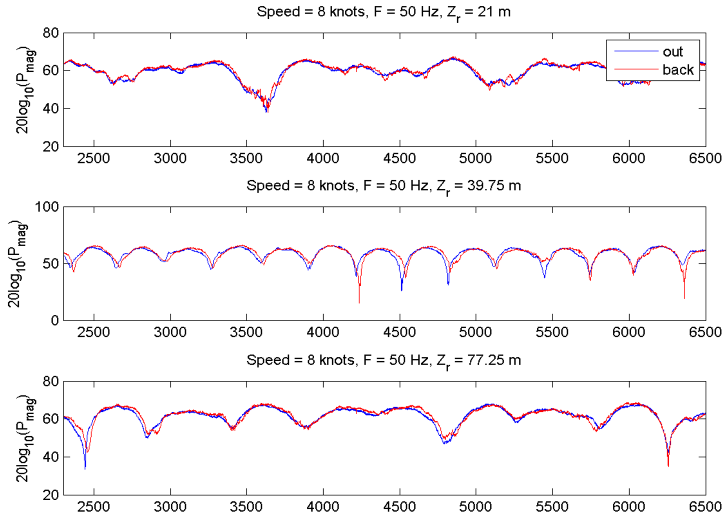

Fig. 1 Magnitude of pressure fields (50 Hz) measured at three depths for source closing and opening in range to the receiver array at 8 knots. Top panel is depth of 21 m, middle panel a depth of 39.75 m, and bottom panel a depth of 77.25 m. Water Column depth was ~80 m.

on the receive array for the source towed at 8 knots toward and back along a radial are shown in Fig. 1. Using techniques based on the short time Fourier transform, the complex pressure field is transformedto the horizontal wave number domain. Individual values of horizontal wave numbers associated with peaks in the horizontal wave number spectrum correspond to propagating normal modes and are used as input data for geoacoustic inversion.

Analysis of the SW06 data seeks solutions to the geoacoustic inversion problem which are optimized for both efficiency and accuracy. Emphasis will be placed on developing methods capable of accounting for range-dependence in the seabed that is both directly measurable, such as bathymetry, and unknown, such as that due to intrusions or layer pinching. To explore range dependence, investigation and application of high-resolution wavenumber estimation techniques [2] will continue. Using wavenumber information as data, geoacoustic parameter estimates will be sought and compared (for both accuracy and algorithm speed) using linear and non-linear approaches. A hybrid inversion method that combines horizontal wavenumber estimation with non-linear optimization methods, where the wavenumber estimates would be used to determine spatially dependent background models for the non-linear parameter search algorithms is being tested. In addition, to improve the depth resolution of perturbative inversion approaches based on *regularization*, an approach is being pursued which allows for discontinuities in the sediment sound speed profile at interfaces [3]. LFM data collected during SW06 will be analyzed in collaboration with S.D. Rajan and results compared for co-located experiments. Additional areas of research based on analysis of the collected data sets include addressing the impact of watercolumn variability on wavenumber estimation [4], development of an exact inversion algorithm based on discrete reflection coefficient data obtained from wave number estimates, and a source depth discrimination tool based on the distribution of energy in horizontal wave number spectra.

WORK COMPLETED

The experimental work described for SW06 was completed in August 2006. During the experiment, this project was allocated 36 hours (12 hours each day 4-6 August, 2006) for acoustic transmissions. At the conclusion of the experiment, 34 hours of data were collected. Over 24 hours of towed cw data were collected along 3 different radials. Tow speeds ranged between 2 and 10 knots. The remaining data were LFMs. LFM data were collected for over 25 different stations on a circle 15 km from the VLA. The acoustic data was retrieved from the VLA/HLA, backed up, and archived for distribution by WHOI. The data were received by the author in December 2006. Algorithms for reducing the raw data to a usable form have been completed. Specific coding has been implemented for demodulating the full time series data into the respective single frequency bands and merging with the spatial track data. Particular care has been to accounting for Doppler shift and spread induced by the moving source to maximize fidelity of the demodulated data. The resulting synthetic aperture data are thus reduced to complex pressure as a function of range from the VLA at each of the transmitted frequencies. Code has also been written to produce spatial representations of the sound velocity field in the water column over each of the acoustic track segments.

RESULTS

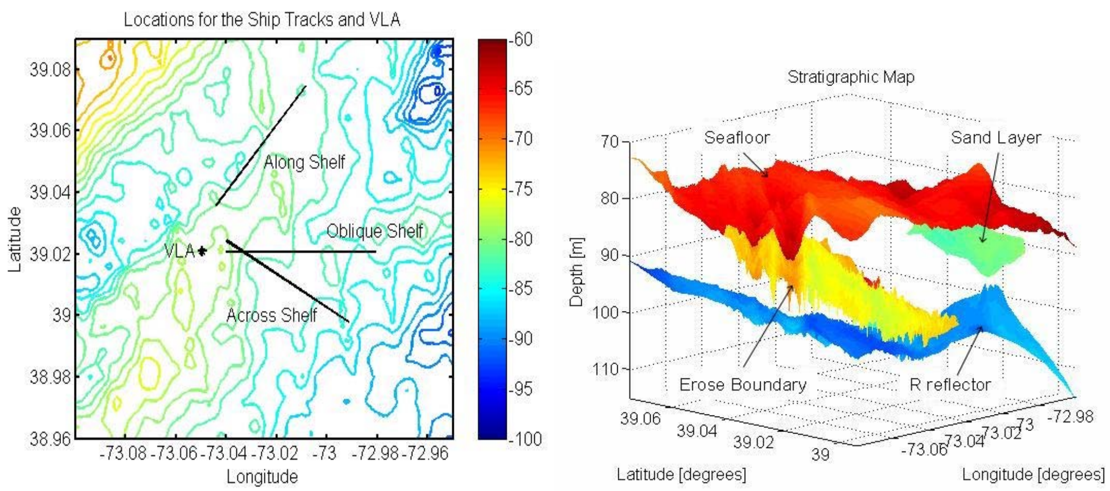

Fig. 2 Geoacoustic inversion was applied to data collected along three source/receiver tracks oriented along, across, and oblique to the shelf bathymetry and indicated in the left panel. Combining the inversion results with high-resolution CHIRP seismic reflection data range-dependent geoacoustic inversion results were extrapolated to cover the area between the tracks. Layer interfaces bounding regions with the same sound speed resulting from the inverion process are indicated in the right panel.

Range-dependent values of horizontal wave numbers were determined for four frequencies along the radial tracks indicated in the left panel of Fig. 2. Using the wave number estimates at each range as input to a linear inversion algorithm based on qualitative regularization, local estimates of the depth dependent sound speed profile in the sediment were obtained. These results are an improvement to range-independent result reported recently [5] where the low-speed layer was not resolved. Based on high-resolution CHIRP seismic data collected in the region of the tracks, a three-dimensional sediment sound speed model was constructed for the area. The three-dimensional layering structure is shown in

the right panel of Fig. 2. Sediment sound speeds within the layers were filled in based on the range-dependent inversion results for the three track lines. The inversion results along the tracks produced consistent results for the sound speeds in the different layers allowing them to be averaged to create the three-dimensional model. For the area nearest the VLA the sediments are represented by two sediment layers over a half-space. The top layer has an average sound speed of 1670 m/s, is ~15 m thick, and runs parallel to the bathymetry. Below this is a layer ~7 m thick with an average sound speed of 1585 m/s that also parallels the bathymetry. The underlying half-space in this region has a sound speed of 1725 m/s. At ranges between 3 and 4 km from the array along the across- and oblique shelf tracks, the low-speed layer is pinched out by the half-space below and the 1670 m/s layer above. At around 3.5 km in the model, a higher sound speed layer at the surface was found. This layer was a few meters thick and has an average sound speed of 1740 m/s and is consistent with a sand ridge. At ranges greater than 4 km, a two-layer over half-space mode persists, with a 1740 m/s top layer, a 15 – 20 m thick layer with sound speed of 1670 m/s, and 1725 m/s half-space. The sand ridge is not present in the Southeast portion of the area and the area is described by the two-layer model with the low speed layer. To evaluate the three-dimensional sediment sound speed model, the acoustic field was predicted using this model for a range-dependent waveguide model crossing the oblique-shelf track shown in Fig. 3. The acoustic field predicted by the model was compared to data taken along this track by other investigators [6] and is shown in Fig. 3. Correlation between measured and predicted fields was greater then 90 percent. Full details of the inversion results and evaluation will be presented in a IEEE JOE journal paper that was recently accepted for publication.

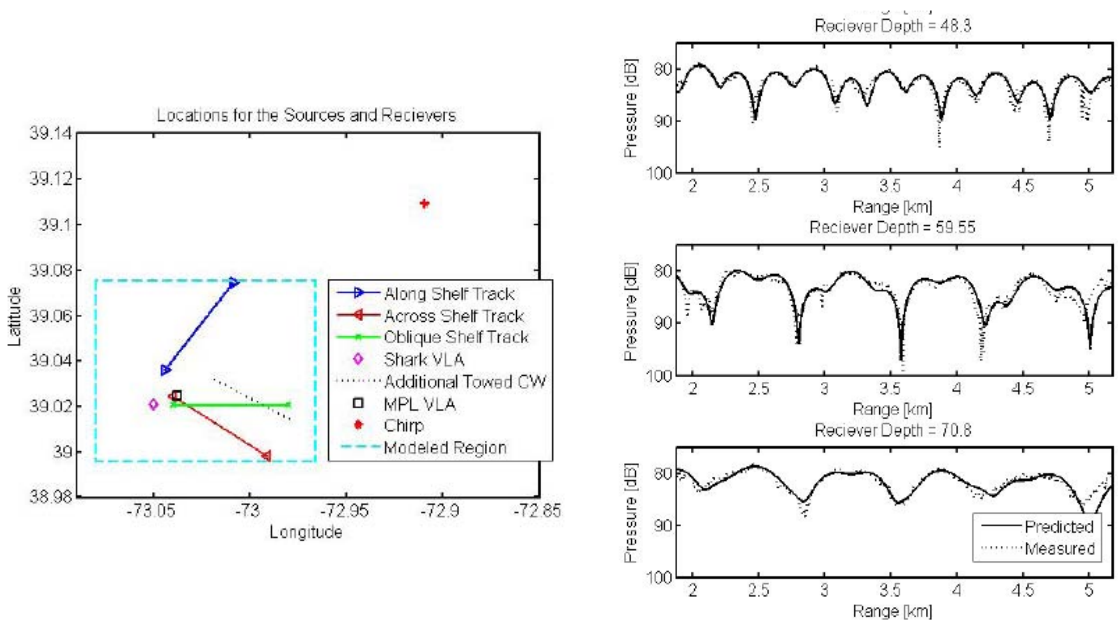

Fig.3 Comparison of acoustic field predicted using inversion results from MIME with data measured along track indicated by dotted line of left panel. The solid lines are the MIME tracks. These data were collected 21 days after data used for inversion and correlation between measured and predicted fields was greater than 90 percent.

The excellent agreement between the measured field and the field predicted using the inferred geoacoutic parameters provides validation of the model for this region. This comparison is a first step in evaluating and synthesizing geoacoustic inversion results from different investigators and methodologies applied to SW06 data. In addition to inversion based on model eigenvalues obtained

from narrowband data, inversion has been carried out using LFM data collected during SW06. Based on modal travel time differences estimated from data measured for multiple source receiver positions,

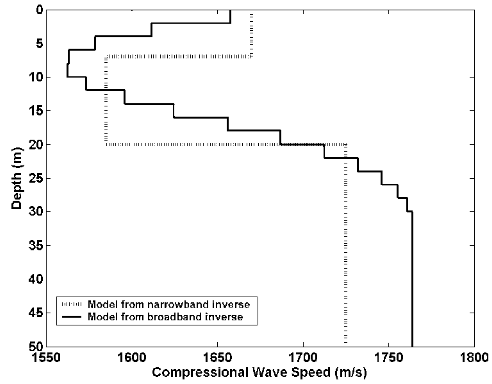

Fig. 4 Comparison of range-averaged sediment sound speed profiles obtained from inversion of narrowband and broadband signals.

geoacoustic inversion for sediment compressional wave speeds was carried out for six regions defining the area between the source locations and the receiver array. The source positions were in an area 15 km to the NorthEast of the VLA. Each of the six regions was characterized by a single sediment sound speed resulting from the inversion algorithm. Although not providing the same spatial resolution as the narrow band inversion results discussed previously, the broadband results showed the same gross features as the narrowband results. In particular, based on the inversion results and consistent with the previous results, the region was characterized by a low-speed sound layer. For the region where the narrowband and broadband data were co-located, the range-averaged sediment sound speed profiles are shown in Fig. 4. As shown, there is good qualitative agreement between the two results, particularly in estimating the extent of the low speed layer. Details of the inversion and results based on the broadband data have been written up and submitted to the IEEE JOE.

IMPACT/APPLICATIONS

The application of these results is for geoacoustic inversion in range-dependent shallow water regions. The results are directed to suggest ways to account for and deal with the variability inherent in the watercolumn in shallow regions. In addition, the high-resolution methods reduce the apertures required to extract modal information resulting in more localized inversion results.

RELATED PROJECTS

This work was a component of SW06. The approaches being developed recognize the complexities of shallow water waveguide environments and seek to account for them. Data and results from these experiments will be shared with and compared with those of other participating PIs. In addition, it is anticipated that the towed CTD chain data will prove invaluable to interpreting results from this experiment and prove itself to be a worth took for consideration in future experimental efforts.

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PUBLICATIONS

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M.S. Ballard and K.M. Becker, "Wavenumber tracking of mesoscale variability in shallow water", in *Proceedings of the 3rd International Conference "Underwater Acoustic Measurements: Technologies & Results"* eds. J.S. Papadakis and L. Bjorno, Nafplion, Greece (21st – 26th June 2009) [published]

HONORS/AWARDS/PRIZES

Graduate Student Megan S. Ballard, working on this project, received best student paper awards at the following conference:

Dec 2008 Acoust. Soc. of Am., Miami, FL - 1st place (lecture) Acoustical Oceanography
M.S. Ballard and K.M. Becker, "Variability of the water column sound speed profile and its effect on the acoustic propagation during the Shallow Water 2006 Experiment", *J. Acoust. Soc. Am.*, **124**(4), pp. 2443 (2008)